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ABSTRACT

This study represents one of the first major summative evaluations of the Science Curriculum Improvement Study (SCIS), a federally funded, six-year elementary science program. An instrument was designed for measuring the effects of SCIS on the stated goal of the curriculum, the development of scientific literacy. Subjects were rural sixth-grade children: 312 had studied SCIS; 219 were otherwise comparable but had not studied SCIS. Results indicated that SCIS contributed to the development of scientific literacy. Specific tasks which differentiated SCIS from non-SCIS students included the identification and control of variables, understanding relative position, and explaining energy transfer. Regardless of SCIS experience, the girls outperformed the boys on the Scientific Literacy Test developed for this study. (Author/BW)

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An Experiment in Curriculum Evaluation:

Science Curriculum Improvement Study
and Scientific Literacy

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Abstract

This study represents one of the first major summative evaluation of the Science Curriculum Improvement Study (SCIS), a federally funded, six-year elementary science program. An instrument was designed for measuring the effects of SCIS on the stated goal of the curriculum, the development of scientific literacy. Subjects were rural sixth-grade children: 312 had studied SCIS; 219 were otherwise comparable but had not studied SCIS. Results indicate that SCIS contributes to the development of scientific literacy. Specific tasks which differentiated SCIS from non-SCIS students include the identification and control of variables, understanding relative position, and explaining energy transfer. Regardless of SCIS experience, the girls outperformed the boys on the Scientific Literacy Test developed for this study.

Introduction

The development of scientific literacy among all segments of our population has been a goal actively supported by many during the past two decades. Multidisciplined teams of curriculum developers, for example, with financial support from the federal government, jointly conceived and carried out extensive research-development projects so that children might grow in their understanding of science. To be scientifically literate has come to mean that one needs to have: (1) a functional understanding of the major ideas in science; (2) knowledge of the history of science; (3) curiosity regarding materials and events; and (4) an understanding of the interrelationships between science and society.

Serious evaluation studies of the federally financed curriculum projects aimed at developing scientific literacy are essential. Currently an estimated thirty percent of the elementary school children in the United States are using one of three curricula developed with the aide of federal funds: Science Curriculum Improvement Study (SCIS), Science--A Process Approach (SAPA), and Elementary Science Study (ESS (Livermore, Private Communication)). All three programs use direct experiences rather than textbooks as the primary media for teaching elementary science.

Although the materials-centered approach was suggested by Pestalozzi as long as 150 years ago, and more recently by Montessori and Dewey, it was not until the major curriculum reform effort of the 1960's that this teaching approach came to be used widely in elementary science education. These non-textbook science curricula need to be assessed to determine (1) their potential for developing a scientifically literate populace, (2) the kinds of science concepts that can be effectively taught to elementary school children through hands-on experience, and (3) the effect of science on the development of children's ability to think logically.

SCIS was one of the major elementary science programs to grow out of the early 1960's when understanding of the structure of a discipline was deemed of utmost importance (Bruner, 1963). The scientists, educators, and psychologists involved in the development of SCIS constructed a sequential program for grades kindergarten through six which reflects the basic principles of science and yet can be taught by ordinary teachers to ordinary students. The stated goal of SCIS is the development of scientific literacy (Karplus, 1964). An overview of the manner in which the SCIS curriculum attempts to realize this goal is described elsewhere (SCIS Teacher's Handbook, 1974).

Evaluation studies concerning the effects of SCIS on children's reasoning have fallen into two broad categories: (1) those yielding data useful to the designers of SCIS in making curriculum decisions and (2) those giving information concerning the cognitive effects of particular units or of one or two year's study of the program.

Studies of the effect of one or two SCIS units suggest that positive effects can be measured in the areas of conservation (Haan, 1968; Stafford, 1969), serial ordering (Almy, 1970), compensating variables (Linn and Thier, 1975), classification (Linn and Peterson, 1973), relative position and motion (Battaglioni, 1972), and utilizing the processes of science (Weber, 1972). However, these results cannot necessarily be generalized to all populations. For example, the socio-economic levels of the children being studied, the teaching style used, and the particular concepts being evaluated proved to be significant variables when analyzing effects of SCIS (Linn and Peterson, 1973; Linn and Thier, 1975; Haan, 1968; Almy, 1970). Studies assessing the cumulative effects of the total curriculum have been

almost nonexistent because of the lack, until very recently, of school systems that have used the program for six consecutive years.

The purpose of the present study was to investigate some of the cumulative effects of SCIS on children's development of scientific literacy. Specifically, scientific literacy in the area of functional understandings of major ideas in science was assessed. It was hypothesized that children who had been exposed to SCIS would evidence a greater degree of scientific literacy than those who had not been exposed to the curriculum. A scientific literacy test was developed and administered to sixth graders in rural Michigan who had used the SCIS program for six years and to an equivalent control group.

Development of the Scientific Literacy Test

Due to a lack of existing measures, a battery of tasks was designed for this study. Seven SCIS staff, three of whom had been with the program since its inception, contributed to the initial phases of the test development. The tasks finally selected for inclusion in the Scientific Literacy Test were justified on the grounds that they represented major scientific concepts central to modern science and were included in the SCIS curriculum. The following criteria were used:

- (1) tasks should be appropriate for eleven and twelve year old children;
- (2) tasks should lend themselves to a pencil-paper, whole class testing situation;

- (3) tasks should form a representative selection of content-process concepts taught in the SCIS program;
- (4) tasks should involve demonstrations, pictures, or other concrete referents;
- (5) tasks should allow for open-ended responses, whenever possible, to permit evaluation of the children's reasoning;
- (6) whenever possible, appropriate tasks already in existence should be revised and used.

Pilot tests were carried out in six classrooms. As a result, the seventeen originally suggested tasks were reduced to nine which composed the final form of the Scientific Literacy Test. Although the test is not totally comprehensive in terms of the major science concepts measured, it does include a subset of basic scientific concepts appropriate for eleven and twelve year old children.

The nine tasks are listed in Table 1. Tasks I-IV examine children's thinking regarding some of the basic processes of science. Tasks V-IX attempt to measure the children's understanding of some of the major content oriented concepts.

An example of task from the test is Analyzing Experiments. In this task children are required to critique experiments in relation to given experimental questions, and/or results. The Analyzing Experiment Task does not resemble any SCIS activity in wording or equipment. A brief description of the procedure and one item will be given.

The following instructions were given to the experimenters administering this task:

"Tell your pupils that you will show them an experiment using the objects on your tray. Hold up the objects one at a time and name them (shoe box with a small hole in one end; one large balloon; one small balloon; fifteen straws). Insert one of the balloon's neck through the hole in the box so that the body of the balloon is inside the box. Partially blow up the balloon; arrange a track of eight to ten straws on a table; place the box on the track, and invite the students to predict what will happen when you release the balloon. Finally, let go of the balloon so the air escapes, causing the box to move. Now distribute the student page and explain that the picture shows the top view of an experiment similar to the demonstration. Read the questions aloud. Invite pupils to get clarification from you individually as you walk among them."

One item from the Analyzing Experiments Task student pages distributed to each of the children is shown in Figure 1.

On the average, each of the nine tasks consisted of four items. Often the items vary within a task in terms of the cognitive demands made of the child. Six of the nine tasks require explanations to accompany discrete answers; one task is open-ended and allows the children to list as many responses as they wish; another gives two distinct problem-solving situations assessed with a total of nineteen multiple choice questions.

All of the tasks chosen for inclusion in the Scientific Literacy Test require the children to perform mental operations, in the Piagetian sense, in order to give evidence of a satisfactory understanding of the concepts. This means that a memorized answer or guess is not sufficient. When written explanations are required it is possible to infer something about the children's thinking processes relative to the specific concept being evaluated. The tasks, a description of what each measures, the specific procedures for administration, and the SCIS activity most closely resembling the task, are reported elsewhere (Borner, 1975).

The validity of the Scientific Literacy Test was estimated by matching the objectives of the curriculum to the test instrument. Table 2 shows the relationship between the stated objectives in the SCIS curriculum and the content of the Scientific Literacy Test.

It will be noted that the Scientific Literacy Test measures more of the stated curriculum objectives from the fourth, fifth, and sixth grade units than from the lower three grades. Also, the test is somewhat weighted in the direction of the objectives of physical science units.

To determine the reliability of the Scientific Literacy Test, test-retest scores for a group of twenty-four children who had experienced varying degrees of SCIS but who were not used in the study were computed. The correlation coefficients ranged between .85 and .97.

Methods

Subjects

A total of 531 middle-class, sixth-grade students from 19 classrooms in a rural area of Michigan participated in this study. The experimental group consisted of 312 children who formed the entire sixth-grade population from two elementary schools; 196 of these students or sixty-two percent of the school population had completed the six year curriculum program in its entirety.

The 219 children who served as controls were selected from three schools that were in close proximity of the experimentals' schools. The control schools for this study were chosen because they were educationally equivalent in terms of socio-economic status and intelligence (Bruce, 1969).

About half the sixth grade students in each school were tested. Principals in both schools claimed that classes in their schools were heterogeneously grouped and that the students tested were a representative sample of their sixth-grade student populations. The control children spent the same amount of time on science per week, approximately one and one half hours, as the SCIS children. The text books used were: Concepts in Science (Brandwein, 1967) and Science in Our World (Schneider, 1961). Scores for the Michigan State Assessment Tests (1971) for the two groups indicated that the ability level of the control group was slightly higher than for the experimentals (experimental mean = 49.9; standard deviation = 8.9; control mean = 51.8; standard deviation = 8.7). The average age of the children in the two groups was the same: twelve years, three months.

Teachers

All the teachers in the experimental schools taught SCIS, not just a selected group of better teachers. No systematic difference existed in the quality or type of teacher hired by the experimental and control school systems. The children tested represented the first group to have used SCIS at each of the different grade levels. It should be pointed out, however, that the teachers' lack of experience may have been compensated for by beginners' enthusiasm.

The two experimental schools used in this study served as SCIS trial centers. These teachers (1) provided feedback to the curriculum developers for use in revising the program, (2) attended an initial workshop prior to their teaching the science program, and (3) received in-service training throughout their first year of using SCIS.

Task Administration

The nine individual tasks were organized into five packets, each containing from one to three tasks. These were distributed in random order to prevent any systematic interaction effects from occurring between tests. Four experimenters administered the group tests. The nineteen classes were each tested in two forty-five minute sessions on successive days. The average amount of time allotted for each task was ten minutes.

The experimenters were each given a standardized set of directions for the administration of the tasks. The recommended procedure for handling student questions concerning test items was to answer each child individually at his desk and refer him to the directions or questions on the student page. The experimenters were asked to record questions the students asked during the testing periods. The only task which consistently elicited questions was the Histogram - Task III. On the average, seven children from each class, regardless of SCIS exposure, requested information regarding the test.

The students' reactions to the testing situation ranged from overt enthusiasm to adamant refusal to work on the activities. Both of these attitudes were rare, however, and were not observed more frequently in either the experimental or control groups. The most usual student response was a positive, cooperative attitude on the first day and a neutral resigned attitude on the second day.

With two exceptions (Histogram Task III, Life Requirements Task VIII), the students either first observed a demonstration experiment using materials relating to the pictures and text on the test pages or hear a description of an experiment accompanied by a presentation of associated data. The experimenter then read orally the student pages to the entire class.

The time allowed for each task appeared sufficient for the majority of the children to complete all of the items. After the allotted time, the experimenter collected the papers or asked the children to turn to the next task in their packet and the sequence was repeated.

Scoring

Scoring criteria was established by the authors. Two persons separately scored three control and experimental classes which served as the raw data for the reliability coefficients. Neither knew the group identity of the papers scored. The remaining sixteen classes were scored by only one person. Scorer reliability was determined to be at the 92% level of agreement.

Results and Discussion

Individual scores from the battery of nine tasks (Table 2) given to the 312 children who studied SCIS (experimental group) and 219 children who did not study SCIS (control group) served as raw data for a multivariate statistical analysis. Multivariate Analysis of Variance was used in this study because scientific literacy could not effectively be encompassed by a single dependent variable (McCall, 1970). The nine task scores were treated as dependent variables; sex and SCIS experience were the independent variables.

Overall, the children with SCIS experience performed better on the Scientific Literacy Test than those without SCIS experience ($F = 13.7$; $df = 9$ and 519 ; $p < .0001$). The results of the multivariate analysis are shown in Table 3.

The tasks which accounted for most of the difference in performance were Variables, Analyzing Experiments, Relative Position, Energy Transfer,

and Solution & Evaporation. Each of these tasks was significant at least at the $p < .01$ level. The Histogram task was significant at the .05 level in favor of the non-SCIS performance. An analysis of the SCIS task score means, according to the number of years the children studied the curriculum, did not reveal any differences due to length of SCIS exposure.

SCIS had the greatest effect in these six areas:

- (1) Identifying significant variables in an experiment (Task I).
- (2) Detecting inadequacies of improperly controlled experiments and suggesting improvements in an experimental design (Task II).
- (3) Explaining experimental results in terms of compensating variables (Task II).
- (4) Mentally putting oneself in another reference frame to communicate positions of objects (Task IV).
- (5) Predicting amounts of transferred energy as indicated by changes in temperature; predicting and explaining temperatures of equal mixtures of warm and cold water (Task VII).
- (6) Using the solution concept to solve a simple proportionality problem (Task IX).

A more detailed description of the data analysis is reported elsewhere (Bower, 1975).

Sex Differences

The girls outperformed the boys on the Scientific Literacy Test ($F = 4.07$; $df = 9$ and 519 ; $p < .001$). The results for the differential performance in terms of sex are shown in Table 4.

The tasks which accounted for most of the sex differences were Variables, Analyzing Experiments, and the Histogram Task which were significant at the .01 level. Further analysis revealed that the SCIS curriculum did not affect one sex more than the other ($F = 1.2$; $df = 9$ and 519 ; $p < .28$).

Research indicates that girls are superior to boys in verbal skills at the ages of twelve and thirteen (Haccoby, 1966). The verbal requirements of the tasks in the Scientific Literacy Test were analyzed and the results are shown in Table 1.

As can be seen, success on the Variables Task I depended upon the form and volume of the written language. Analyzing Experiments Task II required the greatest number of written explanations and the most reading. The Histogram Task III was the second most demanding in terms of the reading requirements. Thus the three tasks which accounted for the sex differences were the most verbally demanding.

Implications

The overall results of the study indicate that northern rural children exposed to the SCIS program assimilate some fundamental ideas of science which are reflective of the basic structure of the discipline. Implicit in this is the fact that SCIS contributes to these children's scientific

literacy development. From an educational point of view, these results have important implications which need to be considered.

First, the data supports and extends the results of other studies which indicate that it is possible to affect children's thinking during the five to thirteen age period with carefully selected manipulative activities. As a group, sixth graders who had direct science experiences were more successful in pencil-paper, problem solving tests requiring logical and scientific thinking than those who used textbooks.

A second point is the amount of classroom input necessary to affect children's scientific and logical thinking. The SCIS intervention, though extended over a six year time period, represents only about five percent of the total teaching time, the same amount of time devoted to the study of science in the textbook oriented control classes. To detect effects of SCIS on children's reasoning abilities, given the relative size of the curriculum input, is impressive.

A third educational implication concerns the fact that not all science concepts are understood with equal success. For example, although the SCIS children as a group did significantly better than the non-SCIS children on the Energy Transfer Task VII, half gave no evidence of understanding thermal energy transfer in spite of the fact that three SCIS activities in the fifth year directly relate to the items in this task.

In contrast, solution, another science concept that was evaluated in the Scientific Literacy Test (Task IX), proved to be very well understood by the SCIS children. Three-fourths could predict and explain what would be left after the liquid from a salt water solution evaporated. In addition, two-thirds could reason about the relative amounts of salt remaining after the

liquid from two solutions evaporates. In contrast, this application of the solution concept to solve a simple proportionality problem was attempted by only 47% of the non-SCIS children. It can be concluded that direct experience with science concepts does not insure understanding.

A final consideration concerns the small absolute differences between the SCIS and non-SCIS children on the Scientific Literacy Test tasks. One measure of the educational importance of the performance differences is the length of time that they can be detected in children's thinking. The data from two tasks in this study (Analyzing Experiments Task II and Relative Position Task V) indicate that curriculum effects in these two areas of logical thinking can be detected for at least two years after they were taught.

Linn and Thier (1973) showed that rural fifth graders who studied the Energy Source unit in SCIS are superior in using compensating reasoning in variables problems than similar children not exposed to the curriculum. One of the items in the Scientific Literacy Test (Task II) also measures this ability and it was found that the curriculum effect is still evident at the end of the sixth grade. Although the task employed by Linn and Thier was different from that used in this study, identical scoring categories were used.

In a second task, Relative Position, another example of sustained intervention effects is evidenced. This notion has been extensively explored from a developmental point of view by both Piaget and Inhelder (1967) and Flavell and Botkin (1968).

In an intervention study, Bataglini (1972) found positive transfer effects of the SCIS fourth grade Relative Position unit immediately after it

had been taught. Our research shows that children, two years after their SCIS study of the concept, are still better able to describe positions of objects from non-self reference frames than comparable children who have not had the unit.

It should be noted that the results of this study are limited in terms of the population to whom they can be generalized. The group of SCIS children evaluated were primarily from a rural section of the northern United States. It has been shown in other studies that rural children tend to score lower in science than do their suburban counterparts (Linn and Thier, 1975; N.A.E.P., 1972).

Further research needs to be conducted to determine (1) if these findings can be extended to other populations of children and (2) whether the SCIS differences are still in evidence in high school and college students.

Footnote

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Table 1
Analysis of Scientific Literacy Test Tasks
In Terms of Verbal Requirements

Task	Writing Requirements	Reading Requirements
I	Variables 1. More variables = higher score 2. The language used to express the variable is scored	17 words
II	Analyzing Experiments 1. Four explanations	194 words
III	Histogram 1. Fill in blanks with numbers	173 words
IV	Reasoning from Data 1. Two explanations--score increases with more attention to detail in explanation	71 words
V	Relative Position 1. No writing requirements	145 words
VI	Energy Source - Energy Receiver 1. Circle choice of answer	89 words
VII	Energy Transfer 1. Two explanations 2. Three number predictions	27 words
VIII	Life Requirements 1. Two explanations	66 words
IX	Solution & Evaporation 1. Three explanations scored for detail 2. Three single word predictions	73 words

Table 2
Total Number of SCIS Objectives for Each Unit and
Number of Objectives Related to Scientific Literacy Tasks

Grade	Number of Objectives in the Physical Science Units	Number of Objectives Covered by Scientific Literacy Test	Number of Objectives in the Life Science Units	Number of Objectives Covered by Scientific Literacy Test
1	60	5 (8%)	49	15 (30%)
2	25	13 (52%)	29	2 (7%)
3	24	8 (33%)	39	9 (23%)
4	7	4 (57%)	11	8 (73%)
5	18	17 (94%)	12	4 (33%)
6	15	7 (46%)	11	4 (36%)

Table 3

Possible Score, Means, Standard Deviations, and Manova Tests of Significance on Scientific Literacy Test Tasks

Possible Score		CONTROL (Had not studied SCIS) N = 219		EXPERIMENTAL (Had studied SCIS) N = 312		Signifi- cance of Difference
		Mean	Standard Deviation	Mean	Standard Deviation	
open	I Variables	4.2	3.1	5.5	3.9	$p < .001$
0-6	II Analyzing Experiments	2.6	1.6	3.1	1.5	$p < .001$
0-10	III Histogram	4.2	2.9	3.7	2.7	$p < .05^*$
0-10	IV Reasoning from Data	6.0	3.0	6.1	2.7	n.s.
0-17	V Relative Position	12.6	2.7	14.5	2.3	$p < .001$
0-5	VI Energy Source- Energy Receiver	3.7	1.1	3.6	1.2	n.s.
0-4	VII Energy Transfer	1.1	1.3	1.4	1.4	$p < .01$
0-4	VIII Life Requirements	1.4	.8	1.4	.8	n.s.
0-10	IX Solution and Evaporation	5.4	2.3	6.1	2.4	$p < .001$

*Direction of significance favors non-SCIS performance

Table 4
Comparison of Means and Manova Tests of Significance
for Boys and Girls on the Scientific Literacy Test Tasks

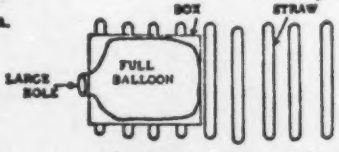
Tasks	Girls (SCIS and Control) N = 247		Boys (SCIS and Control) N = 284		Significance of Difference
	Mean	Mean	Mean	Mean	
I Variables	5.9	4.6	p < .001		
II Analyzing Experiments	3.1	2.8	p < .01		
III Histogram	4.2	3.6	p < .01		
IV Reasoning from Data	6.2	5.8	n.s.		
V Relative Position	13.7	13.6	n.s.		
VI Energy Source - Energy Receiver	3.6	3.7	n.s.		
VII Energy Transfer	1.4	1.2	n.s.		
VIII Life Requirements	1.5	1.3	n.s.		
IX Solution and Evaporation	5.9	5.8	n.s.		

Figure 1. Student Sheet for Task II

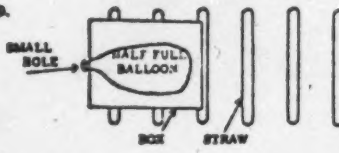
Task II

Mary set up these experiments to find out if the number of straws makes a difference in how far the box goes.

A.



B.



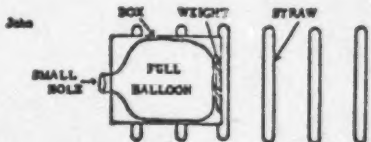
She then tells the class that many straws make the box go further. Her evidence is that it went further in A than in B. Does this evidence show that more straws make the box go further?

yes no can't tell

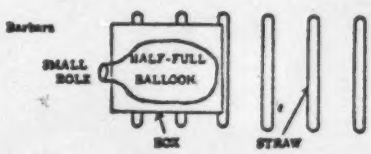
1. Explain your answer.

John and Barbara do these two experiments:

John



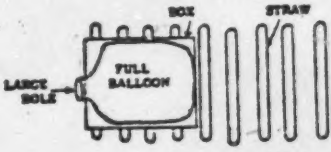
Barbara



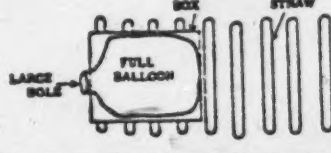
2. They tell you that their boxes went equally far, and can't understand how that happened. Explain it to them.

Mary set up these two experiments to find out if the amount of air in the balloon makes a difference in how far the box goes.

A.



B.



3. John said Mary couldn't find out by doing these experiments. Why did he say that?

Could you improve these experiments about the amount of air in the balloon?

Yes No Can't Tell

4. Explain your answer.
